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BIOMASS FED MICRO-GAS TURBINE PLANT FOR DECENTRALISED ENERGY GENERATION IN TUSCANY

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Outlook

- **Scope of the work**
- **Introduction to biomass in Tuscany**
- **The externally fired gas turbine**
- **Expected performances**
- **Economic analysis**
- **Conclusions**
- **Future work**

Scope of the work (1)

Evaluate the economic feasibility of an Externally Fired Gas Turbine

- ✓ **Bio Micro GT (also called Dual Combustion Gas Turbine DCGT: solid biomass-natural gas)**

as a mean for decentralised Heat and Power production in Tuscany

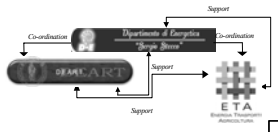
Scope of the work (2)

The work is divided into several different steps

- ✓ **Evaluation of biomass potential in Tuscany**
- ✓ **Definition of MicroGT configuration**
- ✓ **Selection and comparison of different mix of fuels (Dual Combustion with NG or bioethanol, 100 % solid biomass)**
- ✓ **Economic evaluation**

How the work has been carried out
LIFE - BIOSIT
Biomass in Tuscany: a GIS model

- **A wide potential exist in the region**
- **In order to develop bioenergy project → need to assess biomass availability and proper sites for bioenergy generation:**
  - **Technically**
  - **Economically**
  - **Socially**
- **GIS (Geographic Information Systems)**
  - **Essential supporting tool**
  - **Implementation of *ad hoc* algorithms**
- **The GIS analysis identified biomass tyoes and amounts, as well as sites suitable for bioenergy plants**



Definition of 19 Supply Basins

- *Type of avail.resources*
- *Distribution of avail.resources*

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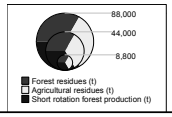
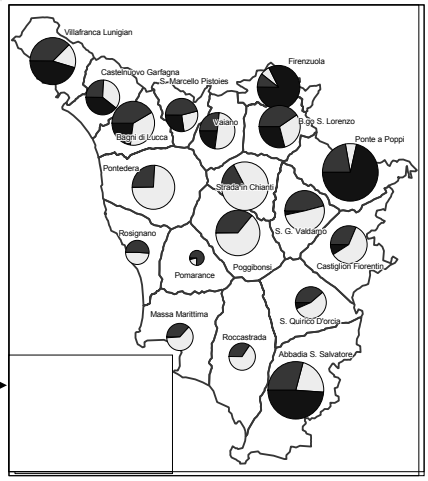
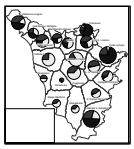


Annual prod.

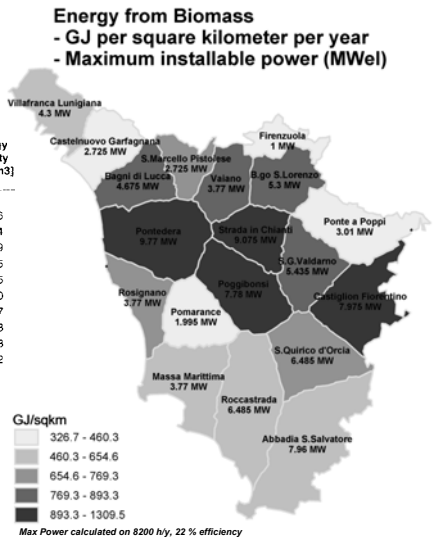


Supply Basin	Economically useful wood residues A (tons/year)	Total Agro-forestry residues B1 (tons/year)	Total Agro-herbaceous residues B2 (tons/year)	SRF Potential Production C (tons/year)	Total present woody residues (tons/year) A+B1	Total present biomass residues (tons/year) A+B1+B2
Villafranca Lunigiana	23,085	10,225	1,668	36108.8	33,310	34,978
Firenzuola	5,558					
Castelnuovo Garfagnana	9,272					
S.Marcello Pistoiese	15,605					
Bagni di Lucca	21,863					
B.go S.Lorenzo	19,981					
Vaiano	10,319					
Ponte a Poppi	19,302					
Strada in Chianti	10,741					
Pontedera	13,818					
S.G.Valdarno	21,909					
Poggibonsi	20,210					
Pomarance	6,155					
Castiglion Fiorentino	12,978					
Rosignano	9,238					
S.Quirico d'Orcia	11,601					
Massa Marittima	8,251	TOT (t/y)	274.049	343.957	295.544	316.468	618.006	913.550
Roccastrada	8,429	15,861	38,150	0	24,290	62,440
Abbadia S.Salvatore	25,734	19,126	32,368	55910.4	44,860	77,228



	Moisture content [wt% w.b.]	GCV [kWh/kg (d.b.)]	NCV [kWh/kg (d.b.)]	Bulk density [kg (w.b.)/m3]	Energy density [kWh/m3]
Wood pellets	10.0	5.5	4.6	600	2,756
Wood chips - hardwood - pre-dried	30.0	5.5	3.4	320	1,094
Wood chips – hardwood	50.0	5.5	2.2	450	1,009
Wood chips - softwood - pre-dried	30.0	5.5	3.4	250	855
Wood chips – softwood	50.0	5.5	2.2	350	785
Grass- high-pressure bales	18.0	5.1	3.8	200	750
Bark	50.0	5.6	2.3	320	727
Triticale (cereals) - high-pressure bales	15.0	5.2	4.0	175	703
Sawdust	50.0	5.5	2.2	240	538
Straw (winter wheat) - high-pressure bales	15.0	5.2	4.0	120	482

Source: S.van Loo, J.Koppejan: "Handbook of biomass combustion and cofiring". IEA Task 32. 2002



Max Power calculated on 8200 h/y, 22 % efficiency

Small scale bioenergy systems

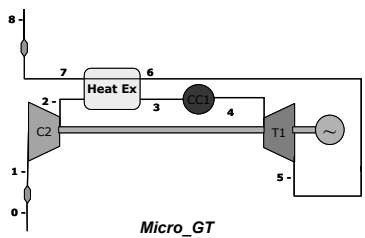
- **Some advantages:**
  - **Easier CHP**
  - **Lower impact on the territory**
  - **Logistic**
- **Disadvantages**
  - **Higher specific cost**
  - **Lower efficiencies**
  - **Lower reliability/availability (power)**

→ ***There's a niche (but significant) market for small scale and reliable bioenergy systems***

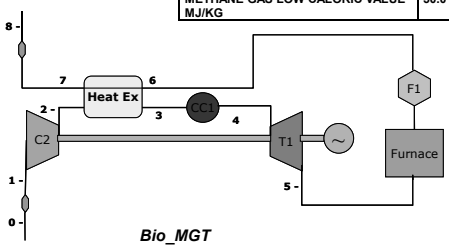
The Bio Micro GT

- **Externally Fired Gas Turbine (Bio_MGT)**
- **Possible integration of internal combustion**
  - **Dual Combustion Gas Turbine**
    - ✓ ***External combustion: solid biomass***
    - ✓ ***Internal combustion: natural gas, liquid biofuel***
  - **It allows for the same TIT**

CYCLE PARAMETER	VALUE
AIR FLOW RATE (KG/S)	0.8
COMPRESSOR, TURBINE POLITROPIC EFFICIENCY	0.85, 0.825
TOTAL PRESSURE RATIO, TIT (K)	4.1, 1183
T AT HEAT EXCHANGER INLET – HOT SIDE (K)	1053
GT COMBUSTOR EFFICIENCY	0.99
BIOCOMBUSTOR EFFICIENCY	0.93
HEAT EXCHANGER EFFECTIVENESS	0.85
MECHANICAL EFFICIENCY	0.98
OVERALL ELEC. SYSTEM EFFICIENCY (WITH INVERTER)	0.92
INLET, OUTLET PRESSURE LOSS (PA)	1000
HEAT EXCH. PRESSURE LOSS, HOT SIDE - COLD SIDE	1.0% - 3.0%
PRESS. LOSS FOR GT COMBUSTION CHAMBER	3.0%
FURNACE PRESS. LOSS WITH EXHAUST FILTER SYSTEM	5.0%
BIOMASS LOW CALORIC VALUE (MJ/KG)	10.7
METHANE GAS LOW CALORIC VALUE MJ/KG	50.0

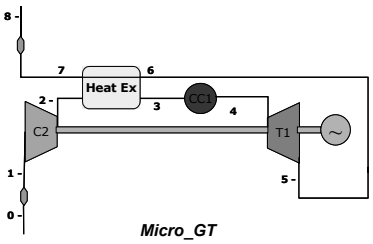


Micro_GT

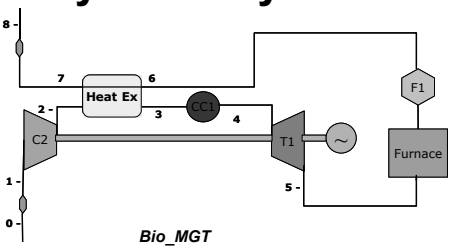


Bio_MGT

Bio Micro GT thermodynamic cycle

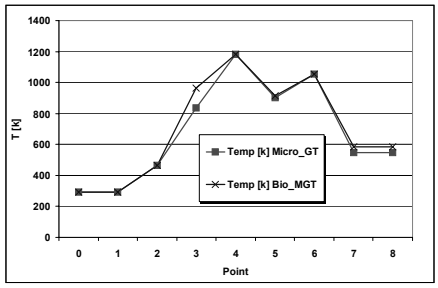


Micro_GT



Bio_MGT

POINT	TEMP. [K] MICRO_GT	PRESS. [KPA] MICRO_GT	TEMP. [K] BIO_MGT	PRESS. [KPA] BIO_MGT
0	293	101.3	293	101.2
1	293	100.3	293	100.3
2	467	411.3	467	411.3
3	836	407.2	965	407.2
4	1183	395.0	1183	395.0
5	902	105.5	914	112.2
6	1053	105.5	1053	105.5
7	549	102.3	585	102.3
8	549	101.3	585	101.3



Bio Micro GT – Expected performances

PERFORMANCE PARAMETER	MICRO_GT	BIO_MGT
NET ELECTRIC POWER (KW)	103	92
EFFICIENCY	31,0	22,1
NATURAL GAS FLOW RATE (KG/S)	0,007	0,004
AIR/GAS FUEL RATIO	121,3	192,8
BIOMASS FLOW RATE (KG/S)	-	0,020
AIR INDEX FOR BIOMASS AVAILABLE	-	8,0
ENERGY BIOMASS CONTRIBUTION	-	51%
EXHAUST HEAT RECOVERY UP TO 373 K (KW)	141,5	174
OUTLET EXHAUST TEMPERATURE (K)	549	585

Bio_MGT

- **Net electric power reduced from 103 kW to 94 kW (~ –5,8%)**
- **Decrease in the electric efficiency, from 31% to ~ 22%, but still very interesting for small scale bioenergy system**
- **Biomass contribution in terms of primary energy > than 50%**
- **Available heat increases from 141,5 kW_{th} to 174 kW_{th} (+23%) → possibility for small CHP**

Economic analysis

- **Capital costs :**

COMPONENT	*COST*	
MICRO GAS TURBINE	132,000	€
BIOMASS BURNER	7,565	€
HEAT EXCHANGER	40,000	€
CYCLONES AND FILTERS	3,000	€
STORAGE OF FUEL	4,000	€
OTHER COMPONENTS	3,000	€
TOTAL	189,565	€

- **O&M costs per year: 6.9 % of total investment costs**

- **Fuel costs:**

67.5 €/t_{DM} (wood chips – 45 €/t at 40 % moisture content)
110 €/ t_{DM} (wood pellets)
22.33 ¢€/Nm3 (natural gas)
0.5 €/lt (bioethanol)

Economic analysis

- **Products:**

4 ¢€/kWh_e (Electricity)
8.41 ¢€/kWh_e (Green Certificate)
6.5 ¢€/ kWh_{th} (Heat – Range: 6-9 ¢€/ kWh_{th})

- **Green Certificates (first 8 years only):**
  - **Applied to all the electric production only if 100 % biomass system.**
  - **Otherwise, applied to 50 % of the renewable energy share (co-firing)**

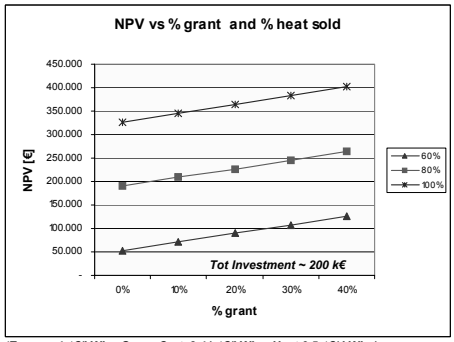
- **Other assumptions:**

DISC,RATE (ON EQUITY)	4 %
EQUIPMENT LIFETIME	12
OPERATING HOURS PER YEAR	6,500
LOAN (%)	60 %
LOAN TERM IN YEAR	8
INTEREST ON LOAN	5,0 %
EQUITY	*40-0 %*
GRANT (SUPPORT)	*0-40 %*

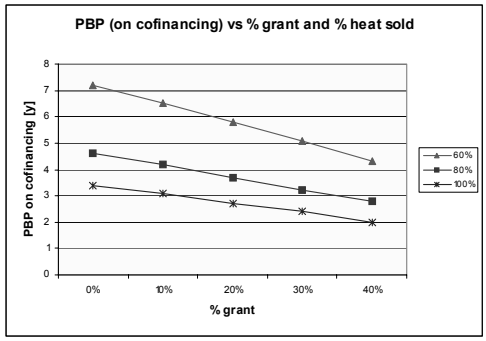
Results – Dual Combustion

NPV & PBP

51 % biomass, 49 % NG



51 % biomass, 49 % NG



(Energy: 4 ¢€/kWh$_e$; Green Cert. 8.41 ¢€/kWh$_e$; Heat 6.5 ¢€/ kWh$_{th}$)

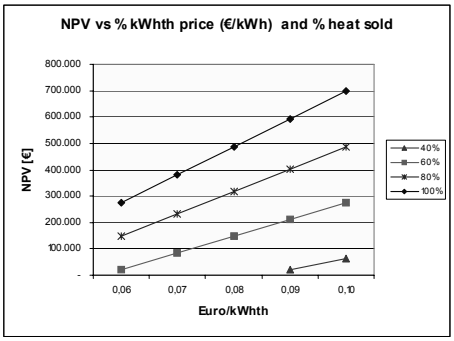
REMARK – As expected, results are more dependent on the amount of heat sold rather than on the grant → income from heat selling is essential for economic viability

Consequence: the success of the bioenergy project depends on its ability to meet existing heat demand, rather than only on public supporting measures

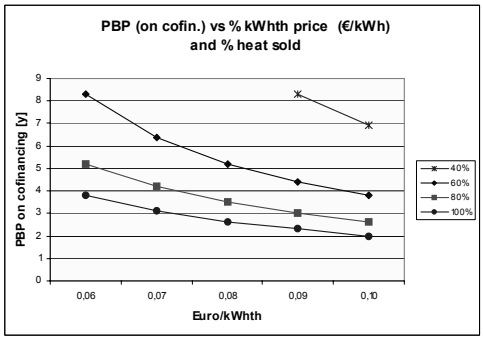
Results – Dual Combustion

Sensitivity on kWh$_{th}$ selling price

51 % biomass, 49 % NG



51 % biomass, 49 % NG



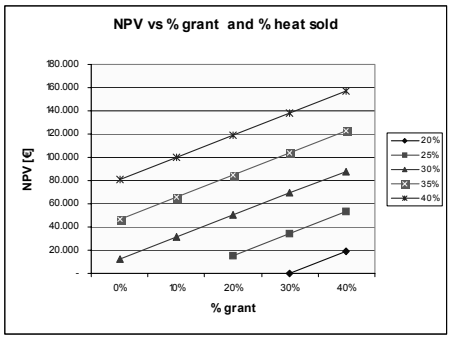
Assumption: 0 % grant, 40 % equity (Energy: 4 ¢€/kWh$_e$; Green Cert. 8.41 ¢€/kWh$_e$; Heat 6.5 ¢€/ kWh$_{th}$)

Result - Project becomes attractive if > 80 % of heat is sold (reasonable PBP time and heat selling price)

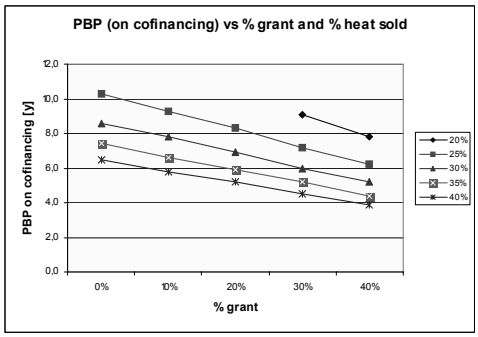
Results – Bio MicroGT

Preliminary simul. on 100 % solid biomass

100 % solid biomass



100 % solid biomass



Assumption: 900 °C TIT. ***(Energy: 4 ¢€/kWh$_e$; Green Cert. 8.41 ¢€/kWh$_e$; Heat 6.5 ¢€/ kWh$_{th}$)***

Results are quite promising, even with low amount of heat placed on the market. Detailed investigation and simulation is worth to be carried out.

Results

100 % biomass, combination of wood chips and bio-ethanol

Assumption:

- ✓ *Hydrated bio-ethanol (92 % v/v) @ 40-55 ¢€/lt (as available in Tuscany)*
- ✓ *Bio-ethanol as substitute of NG in the Dual Combustion mode (49 % of energy input)*

Results are very negative, even assuming 100 % heat sold and 9 ¢€/ kWh$_{th}$

This is due to the high cost of bio-ethanol compared to NG (2.3 ¢€/MJ compared to 0.63 ¢€/MJ of natural gas and 0.6-0.4 ¢€/MJ of solid biomass-chips), which makes the existing incentives – Green Certificates scheme – insufficient for economic viability.

Conclusions (1)

✓Significant potential exists for small scale biomass-based CHP (GIS)

✓Preliminarily examined an externally fired micro gas turbine system (~100 kWe) fed with solid biomass (~ 51 % of energy input) and NG

✓Thermodynamic and performance parameters evaluated. Overall electr. efficiency of 22,1 % obtained keeping 1053 K as T_{max} at H.E. inlet

✓Economic analysis carried out. NPV and PBP calculated. Impact of grant simulated in the range 0-40 %, as well as kWh_{th} selling price.

Conclusions (2)

✓Amount and selling price of heat sold more important than grant

✓Low quality (hydrated) bio-ethanol considered as substitute of Natural Gas: economics are unfavourable

✓100 % externally fired biomass micro gas turbine (no direct combustion of natural gas) preliminary considered. Promising results.

Future Work

- ✓**Identification of a suitable site for installation (on going)**
- ✓**Detailed plant design**
- ✓**Plant construction and testing**